Probability of Success of Interpoint MTR28xxd Converters Used in IMAGE

Dr Henning Leidecker

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Approach:

- Black box: count the number of successes and the total number, and estimate the probability of success as Nsuccess/Ntotal .
- Open the black box:
- Establish the failure mechanism...
- Model it...
- Use model to compute probability.

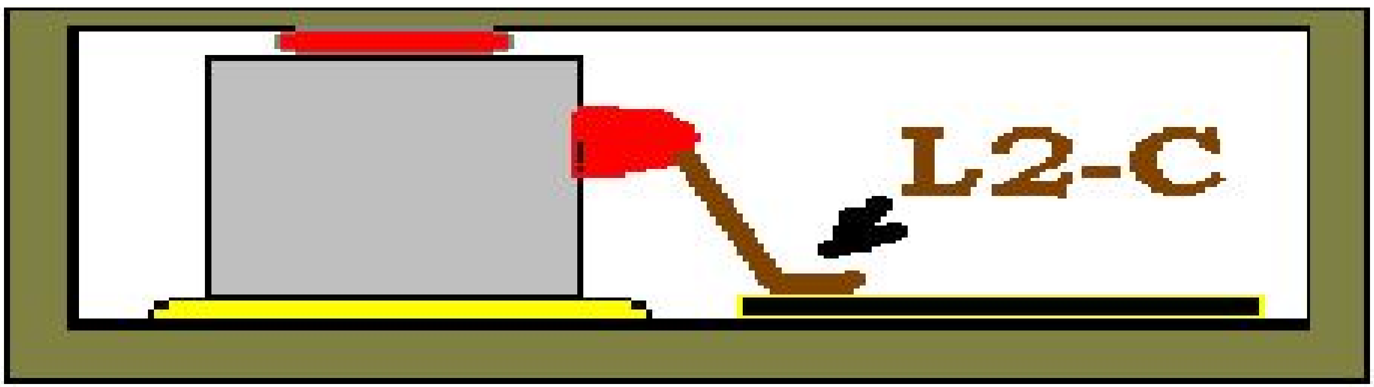
There Have Been Exactly Two Failures of the MTR28xxd Series

- Both failures manifested identically:
  - V? fails as the ambient pressure vanishes.
  - V? returns as ambient pressure is restored.
- Both failure analyses show identical cause:
  - Broken solder connection at pad L2-C.
  - The wire is lifted up as ambient pressure vanishes, and is pressed into the pad as ambient pressure returns.

There Have Been Exactly Two Failures (continued)

- Both failures analyses found the same kind of solder break, caused by Creep to Rupture.
- Not high cycle fatigue --- no fatigue striations.
- Not ductile pull-out --- there are no ductile dimples, and the staking resin cannot provide enough force.
- Not a cold solder joint --- examination of the grain structure confirms this.
- Not caused by incorrect materials, or by contamination --- confirmed by SEM, EDAX, Auger inspections and tests.

Schematic of Cross Section of MTR28xxd, Showing Load Path

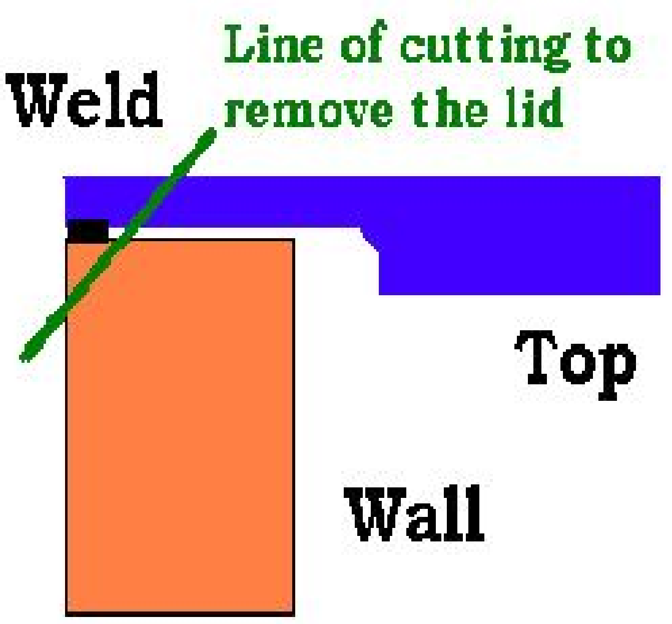


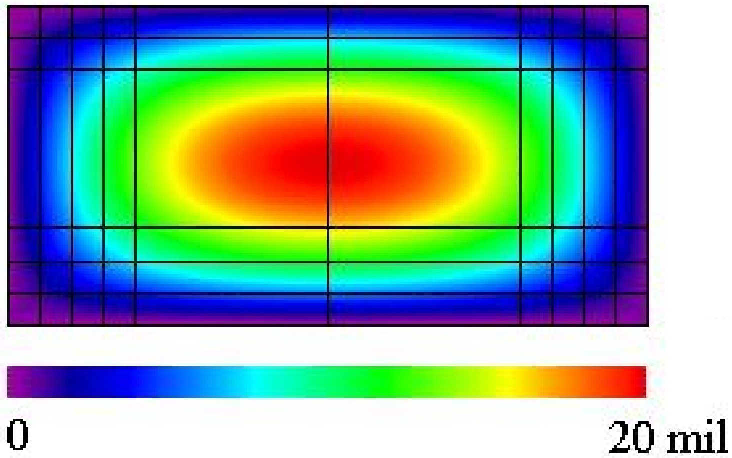
Load Path From Lid to L2-C

- The box is hermetically sealed, so a differential pressure develops as ambient pressure is reduced, and/or the box is heated. The vacuum-force on the lid is about 30 pounds.
- The lid is flexible and moves upwards under differential pressure. The deflection is normally about 10 to 13 mils.
- The inductor L2 is elastically bonded to the bottom and to the top, so it moves upwards as the lid does, about 5+ mils.
- The wire is staked to the side of L2 using an elastic resin. A force of up to a few tenths of a pound is applied to L2-C.

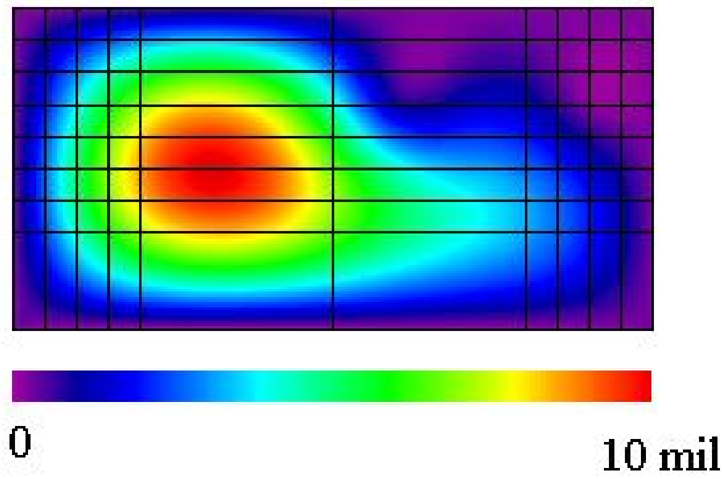
Detail of Lid Attachment

- Conventional DPA grinds along the green line, to remove the weld and release the top.
- However, Interpoint mills the top edge away with ?2 mil-precision. This releases the top cleanly, and prepares the wall’s surface for later re-lidding.
- Delidding at Interpoint is rarely damaging, and even more rarely installs latent defects that survive burn-on, to fail in later use. There are no data showing that re-lidded parts are less reliable than others.





Vertical deformation of lid with magnetics detached. Max deflection $\cong$ 22 mil.

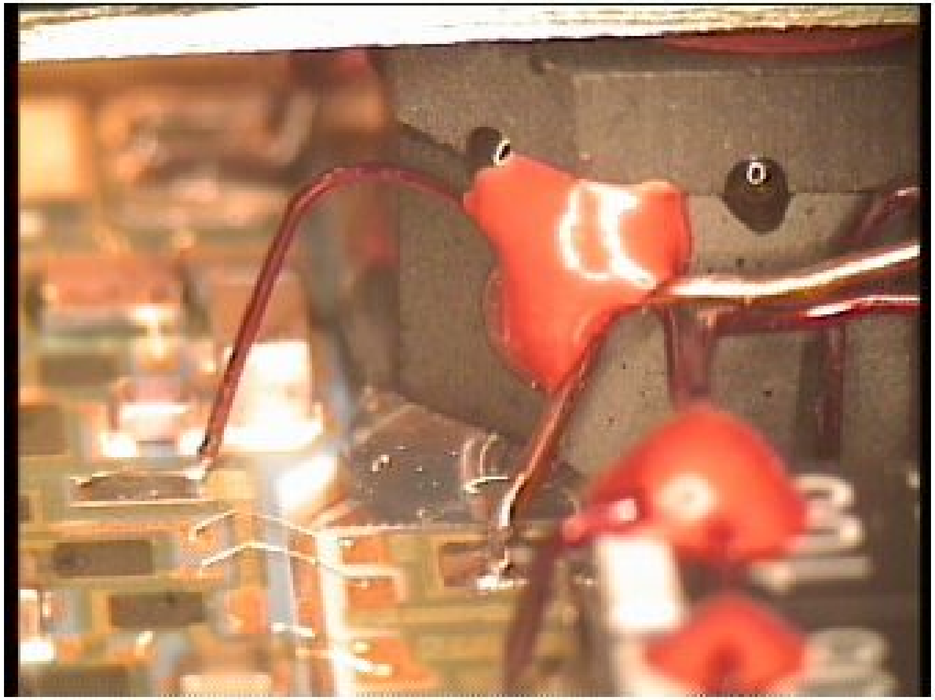


Vertical deformation of lid with magnetics attached. Max deflection $\cong$ 12 mil.

Attachment of wire to inductor: I

- There is much variation in the way the wire is attached.
- The size of the blob of staking adhesive.
- The location of the wire within the blob.
- The stress-relief built into the wire’s shape.
- All these affect the load coupling.

Attachment of wire to inductor: II



Attachment of wire to inductor: III

- Effect of wire size:
- MTR2812/15D uses AWG27 at L2-C
- MTR2805D uses AWG24 at L2-C
- Increasing diameter of wire increases width of soldered area, and decreases the effective stress for a given load.
- Increasing diameter of wire increases "purchase" of staking resin onto wire, and increases the load.
- The effects substantially cancel.
- Implies we can use MTR2805D space history for IMAGE

Creep to Rupture

- Creep rate increases as the sixth power of stress: R ? (stress)6 .
- Creep rate increases exponentially with temperature: R ? exp(- E* / R T) with E* ? 0.9 eV.

Fitting to data, we find the time to rupture:

T = (1700 hr)?(0.4 lb/force)6 ? exp[(9000K)?(1/T - 1/Tref)] .

S/N 0048 Failure (other program)

- The staking material provided a large spring constant for vertical motion of the wire:
- The wire was routed essentially in contact with the inductor; the spacing was less than 0.1 wire diameters.
- The wire passed through the mid-section of the staking resin.
- The reported lifetime was 12 hours at 80 C, which implies a lifting force of about 0.5 pound. This is consistent with the geometry of the wire and staking resin.
- This failure is explained by the load-path analysis, together with the creep-to-rupture rule, applied to the thermal-vacuum history.

S/N 0563 Failure (MAP)

- The staking material provided a large spring constant for vertical motion of the wire:
- The wire was routed close to the inductor; the spacing was less than 0.2 wire diameters.
- The wire passed through the mid-section of the staking resin.
- The reported lifetime was minutes at near 25 C, which implies a lifting force of many pounds, far more than would rip the wire from the staking adhesive.
- This failure is NOT explained by the load-path analysis, together with the creep-to-rupture rule, applied to the thermal-vacuum history.

S/N 0563 Failure (continued)

- The adhesive used to bond the inductor to the bottom of the package escaped over to the pad L2-C.
- During soldering, the entire package is held at 140 C.
- The operator pressed the wire against the adhesive during the time the wire was being soldered, indenting it.
- The operator held the wire in place while the solder cooled, and then moved to the next connection. Inspection at Unisys/GSFC and at SEAL confirms that there was no “cold solder” joint.
- The adhesive continued to press against the wire after the solder had solidified, and caused creep while the solder was slowly cooling from roughly 180 C down to 140 C. This creep substantially damaged the solder connection at L2-C.

S/N 0563 Failure (continued)

- The converter was burned-in at 125 C for 168 hours. The elevated temperature increases the pressure of the dry nitrogen gas within the converter, bowing the lid outward by about 33% of that produced by a vacuum environment. This, and the close spacing of the wire to the inductor, produced additional damage.
- These two events produced the damage that resulted in the failure of the MAP converter during the first cycle. Note the appearance of the rupture crack at the tip of the wire: it is what we expect from the adhesive-induced damage, and it is absent from S/N 0048.
- We must include the bonding resin as a second load path. Then, failure is explained by the load-path analysis, together with the creep-to-rupture rule, applied to the thermal-vacuum history.

Can these failure mechanisms exist in any of the IMAGE converters? Part I.

- The operator is supposed to cut away any resin that intrudes onto a wire. No similar contact between the resin and a wire has been seen in any of the seven converters examined.
- Damage like that in S/N 0563 causes pronounced weakness in the solder joint: an early failure is expected on entering thermal-vacuum testing.
- All the IMAGE converters have already operated long enough in thermal-vacuum to give confidence that no such weakened solder joint had been manufactured into any of them.

Can these failure mechanisms exist in any of the IMAGE converters? Part II.

- The time-to-rupture increases rapidly as the applied force decreases.
- In order to have endured as much thermal-vacuum testing as each MAP converter has, the staking resin must be applying at most a small force.
- If this force decreases slightly, the time-to-rupture increases dramatically, to the two year mission life.
- Comparing the size of the “phase space” of forces that produce a lifetime of longer than times yet shorter than two years, with the entire size of the phase space, gives a probability of failure of substantially less than 1%.